

Article

Comparing Exporting Competitiveness in the EV ERA: Determinants of RCA and REC Among Major Car Exporters

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Abstract

The global shift toward electric vehicles (EVs) may alter the competitiveness of automobile-exporting countries. This study measures revealed comparative advantage (RCA) and relative export competitiveness (REC) and examines their determinants for 10 major automobile-exporting countries from 2001 to 2022. The results show that Mexico, Germany, Japan, and Republic of Korea have strong automobile export competitiveness, Thailand and the United States show moderate competitiveness, while China, Vietnam, Indonesia, and Malaysia record lower RCA and REC values. The regression results indicate that reported EV production status is positively associated with both RCA and REC. Physical capital per worker and labor productivity are also positively associated with competitiveness, while automobile production growth is negatively associated with both indicators. These findings suggest that automobile export competitiveness during the EV transition may depend not only on participation in EV production but also on capital intensity, labor productivity, production efficiency, product quality, and integration into export markets. Policy efforts should therefore support EV-related capabilities while also improving productivity, quality upgrading, and global value-chain integration.

Keywords: revealed comparative advantage (RCA); revealed export competitiveness (REC); export competitiveness; major automobile exporters; determinants of RCA and REC

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1. Introduction

The automobile industry is widely recognized as an important driver of economic growth, employment creation, and technological innovation across many countries [1]. The leading vehicle exporters in recent years have included Germany, Japan, China, Republic of Korea, and Mexico. Germany continues to hold the highest export value, followed by Japan and China, while Republic of Korea and Mexico also remain among the top five exporters. Together, these countries account for the majority share of the global vehicle export market [2].

The automobile industry also plays a significant role in several developing economies in Southeast Asia. Thailand, often referred to as the “Detroit of Asia,” exported close to one million vehicles in 2024 with a total value of about 24 billion US dollars, making

automobiles one of the country's most important export products [3]. Other exporters in the region include Indonesia, Vietnam, and Malaysia, although their export values remain considerably smaller than Thailand's. While the automotive industries of Malaysia and Vietnam are still relatively modest, both countries have been seeking to expand production capacity in recent years.

Despite the increase in automobile exports from countries in Southeast Asia, it remains relatively small in global market share compared to leading exporters such as Germany, Japan, and the United States. In contrast, Thailand and Indonesia each account for a much smaller share of the global car export market. At the same time, the composition of passenger-vehicle exports has changed during the transition toward electric mobility. Figure 1 shows that the share of conventional internal combustion engine (ICE) passenger vehicles in total passenger-vehicle export value declined between 2017 and 2023 in several selected automobile-exporting countries, with the most pronounced changes occurring after 2020. The decline is particularly visible in China, Germany, and Vietnam, while countries such as Indonesia and Thailand continued to show a high share of conventional ICE vehicles in their passenger-vehicle export structure. This contrast suggests that the movement away from conventional ICE exports has been uneven across major automobile exporters.

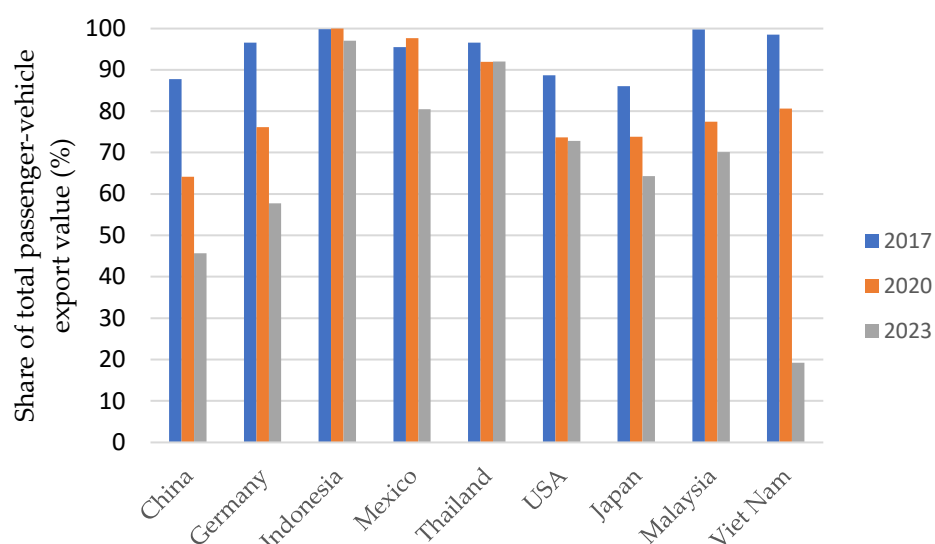


Figure 1. Conventional ICE passenger vehicles declined as a share of export value in most selected automobile exporters, 2017–2023. Note: The figure reports the export value of conventional ICE passenger vehicles as a percentage of total passenger-vehicle exports under HS 8703. Conventional ICE vehicles include gasoline and diesel passenger vehicles. Hybrid and electric vehicles are not included in the ICE numerator. Source: Authors' calculations based on UN COMTRADE and ITC Trade Map data.

Recently, rising demand for electric vehicles has also affected the global automotive industry. Despite being an important participant in EV trade, the United States has experienced a decline in electric vehicle (EV) export value in recent years [4]. Mexico is also a major vehicle exporter, but its share in electric vehicle exports remains relatively low compared with major EV-exporting countries such as Japan, Republic of Korea, Germany, and China [4]. In Southeast Asia, countries such as Thailand, Indonesia, Malaysia, and Vietnam are beginning to develop EV production capacity, but their participation in EV exports remains limited [5–7]. As global demand for EVs rises, the ability to produce and export such vehicles is expected to play a growing role in shaping the international competitiveness of

automobile exporters. This trend is also reflected in the increasing share of electric cars in total new car sales worldwide (Figure 2). The global electric car sales share remained below 5 percent until 2020, increased sharply after 2021, exceeded 20 percent in 2024, and reached about one-quarter of new car sales by 2025. This sharp post-2020 acceleration illustrates the speed of the global transition toward electric mobility.

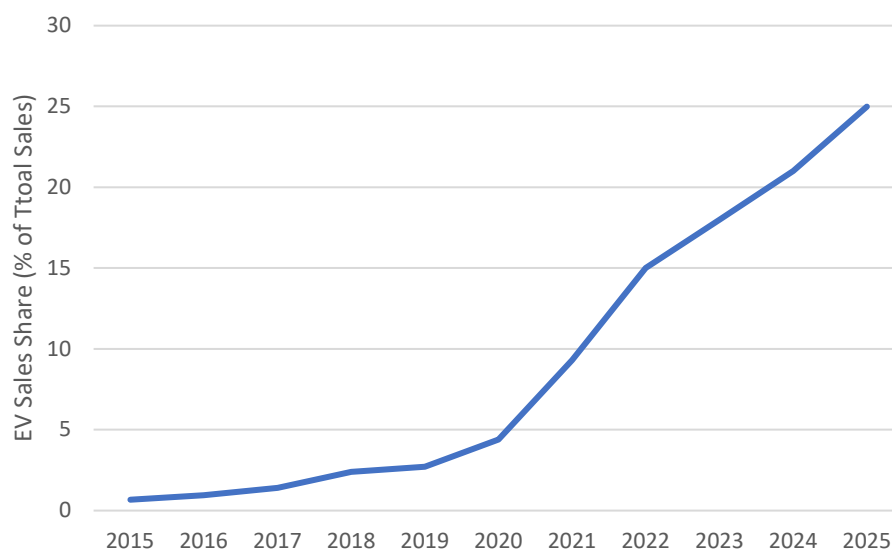


Figure 2. Electric cars rose to about one-quarter of global new car sales by 2025. Source: Extracted from International Energy Agency Global Electric Vehicle Outlook database [8].

In 2024, global EV sales reached about 17.8 million units, an increase of roughly 25 percent compared with 2023. EVs accounted for just over 20 percent of all new car sales worldwide, marking a major milestone in the expansion of the sector. By 2025, electric cars accounted for about one-quarter of total new car sales worldwide, consistent with the trend shown in Figure 2. The global EV fleet grew to nearly 58 million vehicles [9]. EV exports rose nearly 20 percent to about 3.2 million in 2024, with China accounting for around 40 percent of global shipments, the European Union remaining a net exporter, and Mexico sharply increasing exports to the United States [9]. In Southeast Asia, EV sales rose sharply, with countries such as Thailand and Indonesia recording notable increases in their market shares [8,9]. This growth has been supported by government policies, including tax incentives and local production benefits, as well as by rising consumer awareness of EV technology [5–7].

The rise in EVs is reshaping the international competitiveness of automobile exporters. Countries that have traditionally relied on exports of internal combustion vehicles are under pressure to adapt their industries in order to maintain market positions. Competitiveness in trade is grounded in the concept of comparative advantage, which emphasizes specialization in areas of relative efficiency. This means that countries benefit when they focus on activities where they are relatively more efficient than others, thereby building advanced capabilities in specific industries [10,11]. With the rapid growth in EV demand and sales driving major changes in the automobile industry, it becomes important to examine whether this structural shift is altering the revealed comparative advantage and export competitiveness of leading car-exporting countries.

Rather than focusing solely on EV exports, this study examines whether the transition toward EV production is affecting countries' overall competitiveness in total car exports. This distinction is important because the expansion of EV production may influence not only the export of electric vehicles themselves, but also the broader automobile export

position of each country. Countries with stronger EV production capacity may be better able to maintain or improve their overall car-export competitiveness as global demand shifts toward electric mobility, while countries that remain more dependent on conventional vehicle production may face greater pressure to adapt.

To assess competitiveness in the automobile trade, this study employs both Revealed Comparative Advantage (RCA) and Relative Export Competitiveness (REC). RCA measures whether a country has a relative advantage or disadvantage in exporting vehicles, while REC evaluates export performance by comparing a country's share of vehicle exports relative to the rest of the world [12–14]. In this study, RCA and REC are calculated for total car exports rather than for EV exports alone. This allows the analysis to assess whether countries' broader automobile export competitiveness changes during the EV transition rather than measuring EV-specific export performance only. RCA captures revealed export specialization in cars by comparing the importance of car exports in a country's export basket with their importance in world exports. In turn, REC captures relative export competitiveness in the global car market when calculated against world export benchmarks, following the logic of relative export competitiveness measures used by [15]. Using both indicators provides a broader view of automobile export competitiveness than relying on a single measure, although both remain export-based indicators and should not be interpreted as a complete measure of industrial competitiveness; this limitation is consistent with the broader competitiveness literature, which treats trade performance as only one dimension of competitiveness [16].

Previous research has generally analyzed either RCA or REC separately in the context of automobile manufacturing, while others have examined how competitive advantage evolves with economic development and global integration [17,18]. However, little is known about the combined assessment of RCA and REC for the automobile industry in the context of rising EV demand. While earlier studies have treated RCA and REC separately, this paper examines both indicators together for the world's major car exporters. This study compares countries with different levels of EV production capacity to see whether these differences are reflected in variations in export competitiveness.

This study addresses these gaps by first measuring the RCA and REC of total car exports for major automobile-exporting countries over time. It then uses regression analysis to examine whether selected economic, industrial, and EV-related variables help explain variations in these competitiveness indicators. Therefore, the contribution of this study is not simply the simultaneous use of RCA and REC. Rather, this study contributes by combining a dual-indicator assessment of total car-export competitiveness with an explanatory analysis of its determinants, including variables related to the EV transition.

The research question guiding this study is what determines the revealed comparative advantage and relative export competitiveness of total car exports among major automobile-exporting countries, with particular attention given to economic, industrial, and EV-related factors. By addressing this question, this study provides evidence on the determinants of automobile export competitiveness during the transition toward electric mobility. It also clarifies whether EV-related variables contribute additional explanatory insight beyond broader economic and industrial determinants.

2. Materials and Methods

2.1. Data

The data used to calculate RCA and REC included total world exports of merchandise, world exports of automotive products, and the total exports of merchandise and automotive products from 10 major automotive-exporting countries. These countries are China, Germany, Indonesia, Japan, Republic of Korea, Malaysia, Mexico, Thailand, the

United States, and Vietnam. All of these variables were obtained from the World Trade Organization (WTO) database and cover the years 2001 to 2022.

The variables used to analyze the determinants of RCA and REC were drawn from multiple sources. Data on total car production for each country were obtained from the International Organization of Motor Vehicle Manufacturers (OICA). Gross Fixed Capital Formation in current US dollars and the total labor force were taken from the World Bank database. Average capital per worker was calculated by dividing each country's Gross Fixed Capital Formation by its total automotive workforce. This variable is employed as a proxy for capital intensity in the automotive sector since sector-specific data on fixed capital formation are not available. Employment data in the automotive industry, expressed as a percentage of total employment, were sourced from the International Labour Organization (ILO). This share was multiplied by the total labor force to estimate the number of workers employed in the automotive industry. Labor productivity in the car industry was then calculated as total car production divided by the number of automotive workers.

The Competitive Industrial Performance Index, an indicator that measures a country's capacity to expand its presence in international and domestic markets while developing higher value-added industries, was obtained from the United Nations Industrial Development Organization (UNIDO) database. A higher score reflects stronger industrial competitiveness and a higher position in the overall CIP ranking. From the same UNIDO database, the Industrial Export Quality Index was also extracted.

2.2. Measures of REC and RCA

[19] explain that in the classical theory of comparative advantage, based on Ricardo, a country tends to export goods in which it has a comparative advantage. In other words, countries specialize in goods produced by industries with higher productivity. According to their account, the Heckscher and Ohlin model extends this theory by focusing on factor endowments. It predicts that a country will export goods that intensively use the factors in which it is relatively more abundant.

[19] introduced the use of trade flows as an indicator of comparative advantage. This approach measures competitiveness by analyzing a country's export performance in specific goods relative to global averages [20]. If the RCA index is above the expected level, it indicates that the country specializes in exporting that product more than others, signaling comparative advantage. Conversely, a value below the expected level indicates comparative disadvantage.

RCA therefore not only shows whether a country has a comparative advantage but also reflects the degree of that advantage. A higher RCA value indicates stronger specialization in a given industry and greater competitiveness [21]. Ref. [19] further refined this approach by presenting the results in the form of an index number. However, scholars have also noted several weaknesses in Balassa's measure. While Balassa's RCA index remains popular due to its simplicity and minimal data requirements, it has limitations such as skewed value distributions, non-additive properties, incomparability across countries or industries in ordinal and cardinal rankings, and potential double-counting of trade flows [20]. To address these limitations, [16] expanded the RCA measure to account for exports from all countries across all commodities, as shown in Equation (1).

$$RCA_{it} = \frac{X_{iAt}}{T_{it}} \bigg/ \frac{X_{WAt}}{T_{Wt}} \quad (1)$$

where RCA_{it} represents the revealed comparative advantage of country i in automobile exports in year t . i denotes country, t denotes year, A denotes automobile exports, and W denotes the world. X_{iAt} represents the automobile exports of country i in year

t , $T_{i,t}$ represents total exports of country i in year t , $X_{WA,t}$ represents world automobile exports in year t , and $T_{W,t}$ represents total world exports in year t . The numerator, X_{iAt}/T_{it} , measures the share of automobile exports in country i 's total exports. The denominator, $X_{WA,t}/T_{W,t}$, measures the share of automobile exports in total world exports. An RCA_{it} value greater than 1 indicates a revealed comparative advantage in automobile exports, while a value below 1 indicates a revealed comparative disadvantage.

The RCA value is dynamic and can fluctuate due to factors such as trade openness, competitive pressures, and changes in prices or exchange rates [7]. The main advantage of Balassa's RCA index is its simplicity, as it requires only export data, making it easy to calculate and interpret [21]. However, it may overestimate a country's comparative advantage if that country exports only a few products with high export shares. Conversely, countries with more diversified export structures may show lower RCA values for individual products [22].

Another limitation of the RCA index is that it does not account for imports, which can distort results [18]. Furthermore, the index has an asymmetric distribution: comparative advantages range from one to infinity, while comparative disadvantages are confined between zero and one. Despite these shortcomings, Balassa's RCA and [16] refinements remain the most widely applied methodologies in empirical trade research due to their intuitive interpretation and ease of use. Accordingly, this study applies them to evaluate trade competitiveness.

The REC index is applied to measure a country's export competitiveness in the global market [22]. It captures both price competitiveness [23,24] and non-price factors such as R&D-driven quality improvements in OECD countries [18,25–27]. The index evaluates trends in export unit values and changes in market share over time, thereby providing a dynamic view of international competitiveness [28].

The REC index is particularly relevant for emerging economies, where it serves as a tool for identifying areas to strengthen global market performance. Policymakers can use REC results to guide strategies such as investing in product quality and diversifying export structures, which can enhance competitiveness in international markets. As noted by [17], this multifactor approach also supports evidence-based decision-making that fosters sustainable export growth.

To assess the country's export competitiveness in the automotive industry, this study applies the REC index developed by [15], which builds on the earlier work of [29]. The REC index refines Balassa's Revealed Comparative Advantage (RCA) by addressing its double-counting problem and instead evaluates a country's share of world exports of a given product against its share of world exports of all other products. In this formulation, the rest of the world is defined to exclude the focal country to avoid inflating both the numerator and denominator with the same observations. In formal terms, the REC is defined as Equation (2):

$$REC_{it} = \frac{X_{iAt}}{X_{ROWAt}} \bigg/ \frac{X_{iOt}}{X_{ROWOt}} \quad (2)$$

where REC_{it} represents the relative export competitiveness of country i in automobile exports in year t . ROW denotes the rest of the world, excluding country i , and O denotes all other products excluding automobiles. X_{iAt} represents automobile exports of country i in year t , X_{ROWAt} represents automobile exports of the rest of the world in year t , X_{iOt} represents exports of all non-automobile products by country i in year t , and X_{ROWOt} represents exports of all non-automobile products by the rest of the world in year t . The numerator, X_{iAt}/X_{ROWAt} , measures country i 's automobile export position relative to the rest of the world. The denominator, X_{iOt}/X_{ROWOt} , measures country i 's export position in all non-automobile products relative to the rest of the world.

The REC index provides an intuitive measure of relative competitiveness. When REC is more than one, the country's automotive exports constitute a larger share of global automotive trade than its share in global non-automotive trade, indicating a comparative advantage and stronger export competitiveness. Conversely, when REC is less than one, the country's automotive exports are less significant in the global market than its non-automotive exports, suggesting a comparative disadvantage. In this way, the REC index captures whether automotive exports are disproportionately important in the country's external trade relative to the rest of the world, offering a robust and interpretable indicator of sectoral competitiveness [15,21,28].

2.3. The Determinants of RCA and REC

In the following section, we develop frameworks to study the determinants of comparative advantage and export competitiveness by applying both the RCA and the REC. The RCA index provides a baseline measure of competitiveness by comparing a country's share of exports of a particular product with its share in world exports, while the REC index refines this approach by correcting for double-counting and comparing product exports relative to non-product exports [10,15]. Factors influencing RCA and REC in automotive vehicle production are examined through multiple regression analysis. The selected variables are included because RCA and REC reflect export specialization and relative export performance, both of which are expected to depend on production capacity, factor productivity, capital formation, technological upgrading, and broader industrial competitiveness.

The countries analyzed in this paper are exporters whose patterns of comparative advantage differ depending on their capacity to produce EVs. As refs. [30,31] emphasize, such cross-country differences can be explained by industry-level labor productivity differentials and variations in factor endowments. Accordingly, we compare the comparative advantage patterns of countries with low EV production capacity to those with high EV capacity in order to assess how competitiveness is shaped by structural factors. To capture this empirically, we include a dummy variable that takes the value of one when a country reports EV production and zero otherwise, serving as a proxy for EV production capacity. Countries reporting EV production are expected to be better positioned to adapt their automobile industries to the transition toward electric mobility, which may support stronger specialization and export competitiveness in total vehicle exports. Expanded production capacity enhances supply capabilities and scale economies, allowing countries to increase their share of global EV exports [32–35].

The purpose of including a physical capital formation variable is not to assess the relative capital intensity of the automotive sector, but to provide an additional indicator of investment activity and supply capacity. Ref. [36] argued that physical capital formation in the automotive sector can be viewed as evidence of investment activity driven by past and expected returns from building technological capabilities. The link between investment and ongoing trade can therefore be interpreted as the impact of capital investment, reflecting past success and profitability in shaping trade performance [37]. In the automotive sector, higher capital availability may support production scale, modernization of manufacturing processes, and the ability to meet export demand, making it relevant for both RCA and REC. The results for physical capital are therefore expected to be important for explaining both export competitiveness and comparative advantage.

Labor productivity is also included as a determinant of comparative advantage and export competitiveness. Ref. [38] demonstrates that industry-specific export performance can be explained by the interaction of country-level factor endowments, industry factor intensities, and labor productivity differentials. In Ricardian terms, relative labor productivity differences across sectors generate comparative advantage by lowering unit costs in

the more efficient sectors. For example, ref. [39] show in their study of European regions that higher regional labor productivity is associated with stronger export competitiveness across sectors. This broader evidence suggests that labor productivity plays a central role in improving export competitiveness, including in automotive industries.

GDP per capita growth is included as an explanatory variable, serving as a proxy for dynamic changes in economic development. Faster growth in income per capita is frequently associated with structural changes in trade patterns, including upgrading toward more advanced and higher-quality products. Such processes are expected to improve both comparative advantage and export competitiveness [40]. Finally, the growth of a country's automobile production is considered an independent variable that affects comparative advantage. This variable reflects increases in production capacity: as a country expands its automobile production, its share of automobile exports rises. If this share exceeds the world average, the country gains a comparative advantage [32]. Since comparative advantage is measured by comparing the share of a product in a country's exports to its share in world exports [41], automobile production growth is expected to have a significant and positive relationship with indices of comparative advantage and export competitiveness [19].

Taken together, these explanatory variables form the empirical basis of our framework for analyzing comparative advantage and export competitiveness through RCA and REC indices. Based on the multiple regression framework, the general determinants of the competitiveness index can be specified as follows:

$$CA_{it} = \alpha + \mu_1 + \alpha_1 EVD_{it} + \alpha_2 \ln PK_{it} + \alpha_3 \ln LP_{it} + \alpha_4 \Delta \ln GDP_{it} + \alpha_5 \Delta \ln PDUCT_{it} + \varepsilon_{it} \quad (3)$$

In Equation (3), CA_{it} denotes the competitiveness index for country i in year t . In this study, CA_{it} refers to either RCA_{it} or REC_{it} . EVD_{it} is a dummy variable equal to 1 when country i reports EV production in year t , and 0 otherwise. We transformed the explanatory variables into their logarithmic form to address skewness and non-stationarity [15]. Therefore, $\ln PK_{it}$ is the natural logarithm of physical capital per worker, while $\ln LP_{it}$ is the natural logarithm of labor productivity. The physical capital per worker was obtained by dividing each country's Gross Fixed Capital Formation by its total workforce in the automotive sector. It is worth noting that because data on capital formation within the auto industry was not available, we used the average Gross Fixed Capital Formation per worker as a proxy. $\Delta \ln GDP_{it}$ represents GDP per capita growth, measured as the first difference in the natural logarithm of GDP per capita. $\Delta \ln PDUCT_{it}$ represents automobile production growth, measured as the first difference in the natural logarithm of automobile production. The term μ_i captures country fixed effects, which control for time-invariant country characteristics, while ε_{it} is the error term.

To allow for delayed effects, lag structures are added to GDP per capita growth and automobile production growth. This is appropriate because changes in macroeconomic conditions and production capacity may not affect export competitiveness immediately. The model is therefore estimated separately for RCA and REC. The RCA specification is shown in Equation (4), while the REC specification is shown in Equation (5).

$$RCA_{it} = \alpha_R + \mu_{Ri} + \alpha_{R1} EVD_{it} + \alpha_{R2} \ln PK_{it} + \alpha_{R3} \ln LP_{it} + \sum_{j=0}^{p_R} \beta_{Rj} \Delta \ln GDP_{it-j} + \sum_{j=0}^{q_R} \gamma_{Rj} \Delta \ln PDUCT_{it-j} + \varepsilon_{Rit} \quad (4)$$

$$\begin{aligned}
 REC_{it} = & \alpha_E + \mu_{Ei} + \alpha_{E1}EVD_{it} + \alpha_{E2}LnPK_{it} + \alpha_{E3}LnLP_{it} \\
 & + \sum_{j=0}^{p_E} \beta_{Ej} \Delta LnGDPP_{it-j} + \sum_{j=0}^{q_E} \gamma_{Ej} \Delta LnPDUCT_{it-j} + \varepsilon_{Eit}
 \end{aligned} \quad (5)$$

In Equations (4) and (5), RCA_{it} is the revealed comparative advantage index of country i in year t , while REC_{it} is the relative export competitiveness index. The subscripts R and E indicate that the parameters belong to the RCA and REC models, respectively. α_R and α_E are model-specific constant terms. μ_{Ri} and μ_{Ei} represent country fixed effects in the RCA and REC models. The coefficients α_{R1} , α_{R2} , and α_{R3} measure the relationships between EVD, physical capital, labor productivity, and RCA. Similarly, α_{E1} , α_{E2} , and α_{E3} measure the corresponding relationships in the REC model. The coefficients β_{Rj} and β_{Ej} represent the effects of GDP per capita growth at lag j , while γ_{Rj} and γ_{Ej} represent the effects of automobile production growth at lag j . The lag lengths p_R and q_R refer to the selected maximum lag lengths for GDP per capita growth and automobile production growth in the RCA model, while p_E and q_E refer to the corresponding selected lag lengths in the REC model. The lag index $j = 0$ represents the current-period effect, while higher values of j represent delayed effects.

We also include two broader country-level indicators obtained from UNIDO's database for the Competitive Industrial Performance Index (CIP), including the CIP and the Export Quality Index (EXQIN). CIP is included as a country-level measure of industrial competitiveness. UNIDO defines CIP as a composite measure of industrial competitiveness based on countries' capacity to produce and export manufactured goods, technological deepening and upgrading, and impact on world manufacturing trade and manufacturing value added [42]. EXQIN is included as a country-level measure of export quality within the same framework. The export-quality indicator reflects the structure of manufactured exports, particularly the role of manufactured exports and medium- and high-technology exports. The relevance of export quality to trade performance is well established in the international trade literature. Ref. [43] shows that product quality plays an important role in shaping the direction of trade, while ref. [44] shows that higher estimated quality is associated with larger market shares conditional on price. Ref. [45] further show that export-quality upgrading is associated with income levels and human capital. Its relevance to the automobile sector is also supported by [46], who examines product-level export-quality measurement in the Asian motor vehicles sector.

These indicators are relevant to automobile export competitiveness because the automobile industry is a manufacturing-intensive sector in which production capacity, technological capability, product quality, and manufactured export performance are important. Countries with stronger industrial competitiveness and more advanced export structures are generally better positioned to develop sectors with higher value added and higher technological content [42]. However, because CIP and EXQIN are country-level indicators, their effect on automobile RCA and REC is expected to be indirect rather than automatic. They are therefore included to test whether broader industrial competitiveness and export-quality conditions help explain sector-specific automobile export competitiveness beyond automobile production growth, EV production capacity, labor productivity, capital formation, and GDP per capita growth. The addition of EXQIN and CIP into Equations (4) and (5) yields the following equations:

$$\begin{aligned}
 RCA_{it} = & \alpha_R + \mu_{Ri} + \alpha_{R1}EVD_{it} + \alpha_{R2}LnPK_{it} + \alpha_{R3}LnLP_{it} \\
 & + \sum_{j=0}^{p_R} \beta_{Rj} \Delta LnGDPP_{it-j} + \sum_{j=0}^{q_R} \gamma_{Rj} \Delta LnPDUCT_{it-j} \\
 & + \sum_{j=0}^{z_R} \delta_{Rj} CIP_{it-j} + \sum_{j=0}^{s_R} \theta_{Rj} EXQIN_{it-j} + \varepsilon_{Rit}
 \end{aligned} \quad (6)$$

$$\begin{aligned}
 REC_{it} = & \alpha_E + \mu_{Ei} + \alpha_{E1}EVD_{it} + \alpha_{E2}LnPK_{it} + \alpha_{E3}LnLP_{it} \\
 & + \sum_{j=0}^{p_E} \beta_{Ej} \Delta LnGDPP_{it-j} + \sum_{j=0}^{q_E} \gamma_{Ej} \Delta LnPDUCT_{it-j} \\
 & + \sum_{j=0}^{z_E} \delta_{Ej} CIP_{it-j} + \sum_{j=0}^{s_E} \theta_{Ej} EXQIN_{it-j} + \varepsilon_{Eit}
 \end{aligned} \quad (7)$$

In Equations (6) and (7), CIP_{it-j} represents the Competitive Industrial Performance Index of country i at lag j , while $EXQIN_{it-j}$ represents the Export Quality Index of country i at lag j . In Equation (6), δ_{Rj} measures the relationship between CIP and RCA at lag j , while θ_{Rj} measures the relationship between $EXQIN$ and RCA at lag j . In Equation (7), δ_{Ej} measures the relationship between CIP and REC at lag j , while θ_{Ej} measures the relationship between $EXQIN$ and REC at lag j . The terms z_R and s_R denote the selected maximum lag lengths for CIP and $EXQIN$ in the RCA model, while z_E and s_E denote the selected maximum lag lengths for CIP and $EXQIN$ in the REC model. Following [47] and given the relatively short time-series dimension of the panel, we limit the lag structure to one period in Equations (6) and (7).

Equations (6) and (7) are estimated using a country fixed-effects panel specification. Using the fixed-effects approach is appropriate because the analysis focuses on a defined group of major automobile-exporting countries and controls for time-invariant country characteristics, including geography, long-standing industrial structure, institutional conditions, and accumulated manufacturing capabilities. The models are implemented using panel Estimated Generalized Least Squares (EGLS) with cross-section weights and panel-corrected standard errors to account for heteroskedasticity and contemporaneous correlation across countries.

The specification also includes lagged explanatory variables to allow for delayed relationships between production, macroeconomic conditions, and export competitiveness. Although variables such as labor productivity, physical capital, and automobile production growth may have reciprocal relationships with RCA and REC , instrumental-variable or dynamic General Method of Moments (GMM) estimation is not adopted in the baseline model. A credible IV strategy would require valid external instruments, while dynamic GMM estimators are generally designed for panels with many cross-sectional units and relatively few time periods. Since this study uses a focused panel of major automobile-exporting countries, the fixed-effects specification is applied as the most appropriate empirical strategy for the research objective.

3. Results and Discussion

3.1. RCA and REC in the Automotive Industry of Major Exporting Countries

The results from Figure 3 show that the United States, Republic of Korea, Germany, Japan, and Mexico have maintained RCA values greater than 1 since 2000, while Thailand's RCA has been above 1 since 2008. These results indicate that these countries hold a comparative advantage in automobile exports. This finding is consistent with [48], who

confirmed that Mexico and Republic of Korea have strong RCA in auto exports due to the competitiveness of labor and production environments. Ref. [49] also found that Germany has both a high RCA and REC in the vehicle manufacturing sector. Japan and Mexico show RCA values greater than 2, higher than those of the other countries. In contrast, China, Indonesia, Vietnam, and Malaysia all record RCA values below 1, indicating lower revealed specialization in automobile exports rather than necessarily lower absolute production capacity or export strength. China's result is consistent with previous evidence identifying a revealed comparative disadvantage in China's transport-equipment sector [50]. These patterns should be interpreted as evidence of relative specialization rather than absolute production strength. A country may be a large producer or exporter of vehicles but still record a lower RCA if automobiles represent a relatively small share of its total export basket. Conversely, countries with smaller economies may record higher RCA or REC values when automobile exports occupy a more central position in their trade structure.

For REC (bottom left and right panels of Figure 3), the results also highlight differences in competitiveness. Mexico, the United States, Republic of Korea, Germany, Japan, and Thailand all display REC values greater than 1, indicating relative export competitiveness in automobile trade (Figure 3). Mexico shows the strongest REC performance, with a sharp upward trend beginning in 2005 and reaching its highest level in 2020, followed by Japan, Germany, Republic of Korea, Thailand, and the United States. Meanwhile, China, Indonesia, Vietnam, and Malaysia continue to show REC values below 1, pointing to lower relative export competitiveness in the automobile trade. Importantly, countries such as Japan and Mexico combine RCA values above 2 with REC values above 1, confirming both strong specialization and relative export competitiveness in line with the global shift in vehicle trade.

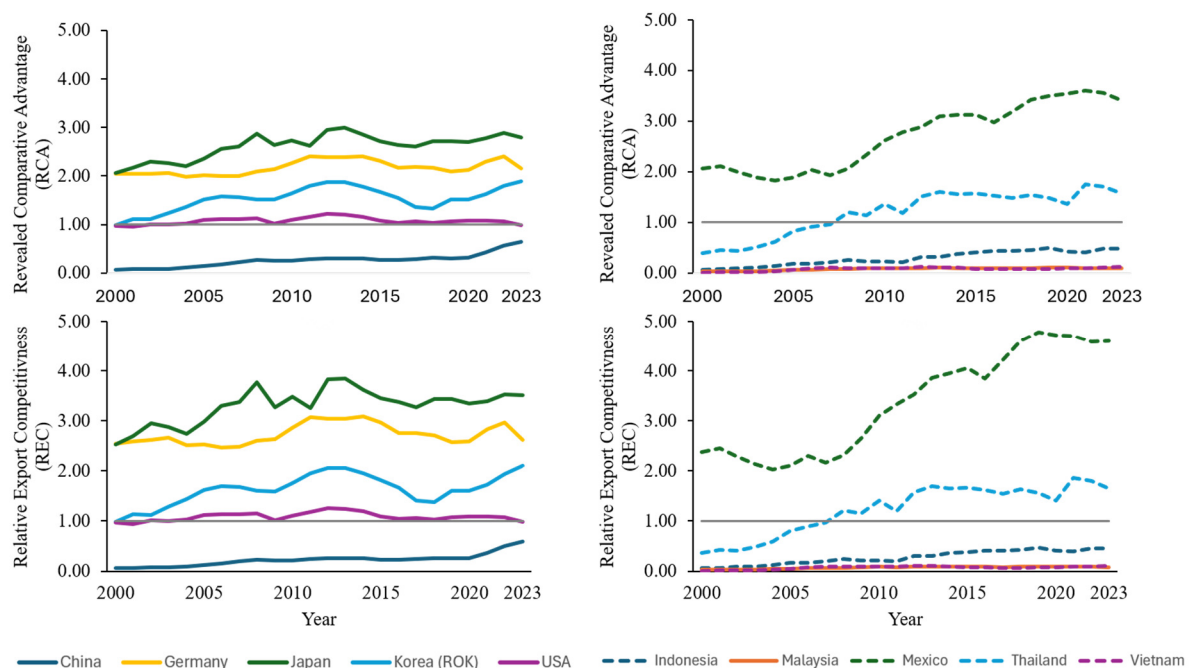


Figure 3. RCA and REC estimates in the automotive industry of major exporting countries. Note: The figures are REC and RCA calculations based on Equations (1) and (2).

Country-specific factors further explain these differences. China represents a special case and should not be interpreted as uncompetitive in absolute terms. RCA and REC are relative trade indicators that measure export specialization and relative export competitiveness. Because China has a highly diversified export structure, automobiles account for

a smaller share of its total merchandise exports, which mechanically lowers its RCA. It is worth noting that much of China's automobile production serves its large domestic market, limiting the extent to which production scale is reflected in export-based competitiveness indicators. Overcapacity, aggressive price competition in the EV segment, and limited brand recognition abroad also constrain its relative competitiveness despite rapid innovation [51,52]. This finding underscores that high absolute production, even in EVs, does not automatically translate into revealed comparative advantage or higher REC values. Nevertheless, there has been an uptick in both RCA and REC values for China, suggesting the possibility of catching up with other countries.

Vietnam's automotive industry remains underdeveloped, with low localization rates and heavy reliance on imported parts [53,54]. Malaysia's smaller export scale, deficits in automotive parts trade, and the dominance of foreign manufacturers limit its ability to build a strong export base [55]. These combined challenges help explain why Vietnam and Malaysia, like China, continue to show RCA values below 1 and REC values below 1, reflecting lower revealed specialization and weaker relative export competitiveness in global automobile exports.

When considering RCA and REC together in the context of rising demand for electric vehicles, three groups of countries can be identified. First, Mexico, Japan, Germany, and Republic of Korea show sustained automobile export competitiveness, with RCA and REC values generally above 1 across the period. Mexico and Japan display the strongest REC performance, while Germany and Republic of Korea also maintain clear revealed specialization and relative export competitiveness. Because RCA and REC in this study are calculated using total vehicle exports rather than EV exports alone, these results should be interpreted as evidence of broader automobile export specialization and relative export competitiveness, not as direct evidence that EV production capacity determines RCA or REC. In the case of Japan, its competitiveness is associated with advanced manufacturing capabilities, strong global brands, and leadership in hybrid technology, which may support its adaptation to the EV transition. Mexico's competitiveness is also associated with its proximity to the United States, one of the world's largest automobile markets, which facilitates trade and integration into North American supply chains.

Second, Thailand and the United States form a moderate group, with RCA and REC values generally around or above 1 but below the strongest exporters. Thailand's advantage is associated with specialization in one-tonne pickup trucks, while the United States combines large production capacity with strong domestic demand but faces competition from Mexico as a neighboring supplier. Third, China, Vietnam, Indonesia, and Malaysia show lower relative automobile export competitiveness, with RCA and REC values below 1 for most or all of the period. In China, high absolute EV output does not automatically translate into RCA or REC for total vehicle exports because automobiles account for a relatively small share of China's overall export basket, and much of its vehicle output is absorbed domestically. In Vietnam, Indonesia, and Malaysia, lower RCA and REC values are associated with smaller production scale, less advanced technology, weaker integration into global automotive value chains, and challenges in developing domestic brands. These factors may also limit their ability to benefit from the growth of the EV market, although the RCA and REC estimates themselves refer to total vehicle exports rather than EV exports alone.

3.2. Determinants of REC and RCA

Countries with electric vehicles ($EVD = 1$) have, on average, 0.169 higher RCA units than countries without electric vehicles ($EVD = 0$), holding other factors constant. Similarly, for REC, countries with electric vehicles show, on average, 0.195 higher units compared to those without. Both results are statistically significant at the 1% level. Recently,

global demand for electric vehicles increased by over 25% year-on-year in 2024, accounting for more than 20% of new car sales, with notable growth in Southeast Asia, Latin America, and Africa [9]. In Thailand, EV market shares have risen sharply, with exports expanding alongside domestic demand [8]. Therefore, EV production capacity is positively associated with RCA and REC, suggesting that countries participating in EV production tend to display stronger overall automobile export specialization and relative export competitiveness. This finding aligns with the earlier RCA and REC results, where countries with high competitiveness also experienced rapid EV production growth.

As shown in Table 1, another set of variables that positively influence RCA and REC are $LnPK$ and $LnLP$. Because $LnPK$ and $LnLP$ are expressed in natural logarithms while RCA and REC are in levels, their coefficients are interpreted as semi-elasticities. A 1% increase in physical capital per worker is associated with an increase of approximately 0.00069 RCA units and 0.00064 REC units. Similarly, a 1% increase in labor productivity is associated with an increase of approximately 0.00067 RCA units and 0.00064 REC units. Although the marginal effects per 1% change are small, the positive and statistically significant coefficients indicate that capital intensity and labor productivity are systematically associated with stronger automobile export competitiveness. The positive effect of physical capital per worker is consistent with expectations, since investment in the automotive sector fosters technological upgrading [36], which shapes trade performance [37]. Likewise, higher labor productivity increases RCA and REC, consistent with [38], who found that productivity differentials strengthen comparative advantage and competitiveness. [56] also emphasize that higher productivity reduces unit costs, allowing firms to charge lower prices and improve export performance.

The results should therefore be read within the fixed-effects panel framework, which is designed to evaluate systematic within-country relationships in automobile export competitiveness over time. The use of country fixed effects, lagged variables, and corrected standard errors strengthens the robustness of the estimates, although reciprocal relationships between competitiveness, productivity, investment, and production remain possible.

Table 1. Findings of the determinants of RCA and REC.

Variable	RCA		REC	
	Coefficient	Std. Error	Coefficient	Std. Error
C	1.009	0.144	1.221	0.144
EVD	0.169 ***	0.051	0.195 ***	0.056
$LnPK$	0.069 ***	0.015	0.064 ***	0.015
$LnLP$	0.067 ***	0.016	0.064 ***	0.016
$\Delta LnGDPP$	−0.138	0.281	−0.152	0.281
$\Delta LnGDPP_{t-1}$	−0.117	0.260	−0.059	0.263
$\Delta LnPDUCT$	−0.044 ***	0.013	−0.041 ***	0.013
$\Delta LnPDUCT_{t-1}$	−0.018 *	0.011	−0.017	0.011
CIP	−1.154	0.962	−0.761	1.072
CIP_{t-1}	0.604	0.929	0.257	1.011
$EXQIN$	−0.170	0.226	−0.198	0.227
$EXQIN_{t-1}$	−0.032	0.231	0.001	0.232
R^2	0.986		0.983	
$Adj R^2$	0.985		0.981	

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.

$\Delta LnPDUCT$ has a significant negative effect on both RCA and REC. Since $\Delta LnPDUCT$ is measured as a log difference, the RCA coefficient of −0.044 implies that a 1% increase in

automobile production growth is associated with an approximate decline of 0.00044 RCA units. The corresponding REC coefficient of -0.041 implies an approximate decline of 0.00041 REC units. Although these marginal effects are small for a 1% change, they are statistically significant and indicate that production growth alone does not necessarily translate into stronger revealed specialization or relative export competitiveness. This result is counterintuitive relative to the expectation that expanded production capacity should support export performance. However, RCA and REC are export-based indicators, so production growth improves these measures only when additional output is reflected in stronger export shares relative to the relevant benchmark. This negative effect can also be explained by rising costs and overcapacity. Firm-level evidence shows that increases in unit labor costs reduce export performance, particularly among labor-intensive producers [57]. Similarly, competitiveness indicators based on unit labor costs are closely linked to changes in export market shares, underscoring that output growth does not necessarily improve trade performance when accompanied by higher costs [58]. In addition, overcapacity in the automobile sector, as observed in China, demonstrates how production expansion beyond demand forces firms to cut prices, eroding margins and competitiveness [59]. These results suggest that growth in production, without efficiency gains or export absorption, may weaken comparative advantage.

Finally, the $\Delta \ln GDP$, CIP and $EXQIN$ are found not to have a significant impact on RCA and REC. This does not imply that broader economic development, industrial competitiveness, or export quality are unimportant. Rather, the results suggest that, within this specification, variation in RCA and REC is more directly associated with automobile-sector variables such as EV production capacity, capital intensity, labor productivity, and production growth. This may indicate a gap between broader country-level industrial competitiveness and export quality, on the one hand, and sector-specific automobile export competitiveness, on the other, since national industrial strength does not automatically translate into stronger RCA or REC in a specific industry.

A limitation of the empirical specification is the possibility of endogeneity between some explanatory variables and the competitiveness indicators. In particular, labor productivity, physical capital, and automobile production growth may not be strictly exogenous since higher automobile export competitiveness may also support investment, productivity improvements, and production expansion over time. For this reason, the estimated coefficients should be interpreted as conditional associations rather than definitive causal effects. The use of country fixed effects helps account for time-invariant country heterogeneity, while the inclusion of lagged variables allows for delayed relationships. However, these procedures do not fully eliminate the possibility of reverse causality or omitted time-varying factors. Dynamic panel approaches such as difference or system GMM are designed for settings with endogenous regressors, but they are generally developed for panels with many cross-sectional units and relatively few time periods. Given the small number of countries in this study, applying GMM would require strong assumptions and careful instrument validity testing. Future research could extend the analysis using instrumental variables or dynamic panel estimators if suitable instruments and a larger country sample become available.

4. Conclusions

The automotive industry supports economic growth, generates jobs, and promotes technological advancement in many countries. In recent years, consumers have shown increasing demand for electric vehicles, which has begun to reshape the competitiveness of automobile-exporting countries. This study measured RCA and REC and investigated their determinants using multiple regression analysis. The results show that Mexico, Germany, Japan, and Republic of Korea hold a strong competitive advantage, while Thailand

and the United States show moderate competitiveness. By contrast, countries with lower RCA and REC values include China, Vietnam, Indonesia, and Malaysia.

The regression findings indicate that the presence of EV production is positively associated with higher RCA and REC. Countries classified with EV capacity tend to display greater competitiveness, suggesting that participation in EV is associated with stronger automobile export specialization and relative export competitiveness. Physical capital per worker and labor productivity are also positively related to RCA and REC, consistent with the view that investment and efficiency gains strengthen comparative advantage. By contrast, overall car production growth shows a negative effect on RCA and REC. This result suggests that production expansion alone does not necessarily improve export competitiveness and may reflect cases where output growth is not matched by export demand, efficiency gains, or quality upgrading.

These findings suggest several policy implications. Although the regression results should be interpreted as conditional associations rather than definitive causal effects, the empirical model is grounded in a theoretical framework that links automobile export competitiveness to EV production capacity, capital formation, labor productivity, production growth, industrial competitiveness, and export quality. Therefore, the results can still inform policy priorities by identifying the conditions that are systematically associated with stronger RCA and REC. Since EV production capacity is positively associated with RCA and REC, policies that support EV-related capabilities, including technology upgrading, charging infrastructure, supplier development, and production standards, may help countries strengthen their position in automobile exports. However, the results should be interpreted as conditional associations rather than definitive causal effects, so policy design should account for each country's industrial capacity, market conditions, and export structure. Likewise, improving human capital through training and education programs could raise labor productivity and contribute to export performance. At the same time, the negative coefficient for automobile production growth indicates that governments should avoid relying only on capacity expansion as a competitiveness strategy. Instead, policy should emphasize productivity, quality upgrading, export absorption, and alignment between production growth and external demand. Finally, countries with lower RCA and REC values, such as China, Vietnam, Indonesia, and Malaysia, may benefit from targeted strategies to improve integration into global value chains through international partnerships, trade agreements, supplier upgrading, and the adoption of internationally recognized manufacturing standards.

The scope of the analysis also points to an important direction for future research. The use of total vehicle exports and the EV production dummy reflects the data structure available over the full study period. EV-specific export and production data are not consistently available across countries for the entire 2000–2023 period. This is partly related to trade classification changes, since electric vehicles became more clearly identifiable in international trade data after the HS 2017 reclassification, whereas earlier classifications did not consistently separate EVs from hybrid or other vehicle categories. In addition, the rapid expansion of EV production and exports occurred mainly in the late 2010s, which limits the construction of a balanced long-term panel using continuous EV-specific variables. For this reason, this study calculates RCA and REC using total vehicle exports and includes the EV production dummy as an indicator of whether a country reports EV production in a given year. Future research could extend this approach by comparing ICE, hybrid, EV, and battery-related competitiveness separately as more consistent long-term data become available.

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Abbreviations

The following abbreviations and important notations are used in this manuscript:

BOT	Bank of Thailand
CIP	Competitive Industrial Performance Index
EGLS	Estimated Generalized Least Squares
EXQIN	Export Quality Index
EV	Electric Vehicle
EVD	Electric vehicle dummy variable
GMM	Generalized Method of Moments
ICE	Internal combustion Engine
ILO	International Labour Organization
$LnPK$	Physical capital per worker (in natural logarithmic form)
$LnLP$	Labor productivity (in natural logarithmic form)
$\Delta LnGDPP$	Gross Domestic Product Per Capita Growth Rate
$\Delta LnPDUCT$	Automobile production growth rate
OICA	International Organization of Motor Vehicle Manufacturers
RCA	Revealed comparative advantage
REC	Relative export competitiveness
UNIDO	United Nations Industrial Development Organization
WTO	World Trade Organization

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